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SENSOR FOR DETECTING DROPLET CHARACTERISTICS

Inventors: Henner W. Meinhold, Mark L. Rea, Sachin M. Chinchwadkar, Fred J. Chetcuti, and John S. Drewery

BACKGROUND OF THE INVENTION

1. Field Of The Invention

The present invention relates generally to sensors, and more particularly but not exclusively to sensors employed in integrated circuit fabrication.

2. Description Of The Background Art

Fabrication of an integrated circuit (IC) typically requires deposition of one or more layers of material onto a wafer. The deposited material, which is also referred to as "thin film" or simply "film", is preferably deposited such that it has uniform thickness across the wafer or localized regions of the wafer. As is well know, the more uniform the film thickness, the better. Thus, a technique for facilitating dispensing of uniform amounts of material on a wafer is generally desirable.

SUMMARY

The present invention relates to methods and apparatus for detecting droplet characteristics. Embodiments of the present invention may be used in various applications including, without limitation, in dispensing uniform amounts of materials on a wafer and other workpieces.

In one embodiment, a sensor includes two plates that form a capacitor. A droplet passing between the plates changes the capacitance of the sensor, thereby triggering

an amplifier coupled to the sensor to generate an output signal. The output signal is indicative of droplet characteristics and may be used to calibrate a mechanism that dispensed the droplet.

These and other features and advantages of the present invention will be readily apparent to persons of ordinary skill in the art upon reading the entirety of this disclosure, which includes the accompanying drawings and claims.

DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a schematic diagram of an integrated circuit manufacturing equipment that may benefit from embodiments of the present invention.

FIGS. 2A, 2B, and 2C schematically illustrate portions of a print head that may be employed in the equipment of FIG. 1.

FIG. 3A shows a schematic diagram of an integrated circuit manufacturing equipment in accordance with an embodiment of the present invention.

FIG. 3B shows a schematic diagram of an integrated circuit manufacturing equipment in accordance with another embodiment of the present invention.

FIG. 4 shows a schematic diagram of a sensor module in accordance with an embodiment of the present invention.

FIG. 5 shows a circuit diagram of a sensor module in accordance with an embodiment of the present invention.

FIG. 6A shows a perspective view of a chassis assembly for a sensor module in accordance with an embodiment of the present invention.

FIG. 6B shows a magnified view of a portion of the chassis assembly of FIG. 6A.

The use of the same reference label in different drawings indicates the same or like components.

DETAILED DESCRIPTION

In the present disclosure, numerous specific details are provided, such as examples of apparatus, circuits, components, and methods to provide a thorough understanding of embodiments of the invention. Persons of ordinary skill in the art will recognize, however, that the invention can be practiced without one or more of the specific details. In other instances, well-known details are not shown or described to avoid obscuring aspects of the invention.

Embodiments of the present invention will be described in the context of an integrated circuit (IC) manufacturing equipment. It should be understood, however, that the present invention is not so limited and may be employed in other applications requiring sensing of droplet characteristics.

Referring now to FIG. 1, there is shown a schematic diagram of an IC manufacturing equipment 150 that may benefit from embodiments of the present invention. Other IC manufacturing equipments that may also employ embodiments of the present invention are disclosed in co-pending and commonly assigned US Application 09/823,721, filed on March 30, 2001, by Henner Meinhold, Fred J. Chetcuti, and Judy Huang. The just mentioned US Application is incorporated herein by reference in its entirety.

In equipment 150, an ink-jet print head 120 includes nozzles 121 for dispensing materials on a wafer 102. An example of a print head that may be employed includes that of the type available from Ink Jet Technologies, Inc. of San Jose, California (URL:<http://www.inkjet-tech.com>). It is to be noted that embodiments of the present invention may also be used with other droplet dispensing mechanisms.

Material to be deposited on wafer 102 is contained in material source 110 and dispensed through nozzles 121. The material to be deposited depends on the fabrication process. Examples of materials that may be dispensed using print head 120 include, without limitation, low dielectric constant materials, photoresists, developers, slurries, cleaning liquids, and silica-based solutions such as spin-on-glass.

As shown in FIG. 1, print head 120 may be controlled by a computer 100 via a control system 101. Control system 101 may include data acquisition and control devices for monitoring and controlling print head 120. Control system 101 may also include devices for monitoring and controlling other components of equipment 150 such as material source 110 and one or more transport mechanisms (not shown) for moving print head 120. To deposit material on wafer 102, droplets of the material are dispensed through nozzles 121 while print head 120 is moved across the wafer.

FIGS. 2A-2C schematically illustrate portions of a print head 120 that may be employed in equipment 150. The example print head 120 shown in FIGS. 2A-2C is a print head from Ink Jet Technologies, Inc. It is to be understood, however, that embodiments of the present invention are not limited to sensing characteristics of droplets dispensed from such an ink-jet print head or other droplet dispensing mechanisms.

In the example of FIGS. 2A-2C, a nozzle 121 is coupled to a chamber 201, which in turn receives material from a reservoir such as material source 110 . Chamber 201 is surrounded by a ceramic chamber piece 203 and ceramic nozzle piece 202. A piezoceramic actuator 204 is disposed adjacent chamber 201 as shown in FIG. 2A. Referring to FIG. 2B, applying a low voltage on actuator 204 causes actuator 204 to contract, thereby making chamber 201 expand and draw material from the reservoir. Thereafter, as illustrated in FIG. 2C, applying a high voltage on actuator 204 causes actuator 204 to relax. The resulting pressure surge drives material from chamber 201 and out of nozzle 121.

To obtain uniform film thickness, a multi-nozzle mechanism such as a print head should uniformly dispense droplets onto a wafer. However, due to variations in the manufacture of nozzles and actuators, not all nozzles will dispense droplets the same way. That is, the mass of each droplet (also referred to as “drop mass”) and the speed at which a droplet is ejected (also referred to as “drop velocity”) will vary from nozzle to nozzle. For example, one nozzle may dispense droplets of a certain mass at a certain drop velocity, whereas another nozzle may dispense droplets of another mass at another drop velocity. To compensate for variations in drop mass and drop velocity, embodiments of the present invention advantageously employ a sensor for detecting droplet characteristics. Information obtained from the sensor may be used to calibrate each nozzle so that all nozzles dispense droplets having relatively the same characteristics.

Referring now to FIG. 3A, there is shown an IC manufacturing equipment 350 in accordance with an embodiment of the present invention. Equipment 350 is similar to

equipment 150 shown in FIG. 1 except for the addition of a sensor module 300. Sensor module 300 allows nozzles 121 to be calibrated to achieve relatively uniform drop mass. Sensor module 300 may also be used to calibrate nozzles 121 so that they dispense droplets at a relatively uniform drop velocity.

In one embodiment, sensor module 300 is placed in a location reachable by print head 120. For example, sensor module 300 may be in a maintenance station adjacent to a chamber where wafer 102 is processed. Prior to dispensing material on wafer 102, print head 120 may be positioned over sensor module 300 using a transport mechanism (not shown) such as a motorized single or two-axis stage, for example. A nozzle 121 is then actuated to dispense a droplet through a sensor in sensor module 300, which detects the drop mass. The detected drop mass may be compared to a known good drop mass. The known good drop mass for a particular application may be determined by experimentation, for example. If the drop mass is not within a desired range, the nozzle 121 may be adjusted until it dispenses droplets having the desired mass. For example, if the nozzle 121 employs a piezoceramic actuator, the electrical signal applied on the actuator may be varied to achieve the desired drop mass. The electrical signal needed to be applied on the actuator to dispense droplets having the desired mass may be stored in computer 100, and then used on the nozzle 121 during operation.

Sensor module 300 may also be used to detect drop velocity by measuring the time between dispensing a droplet from a nozzle 121 and detecting the droplet in sensor module 300. This measured time together with the known distance between a nozzle 121 and sensor module 300 may be used to calculate drop velocity. For

example, computer 100 may be alerted when nozzle 121 is fired and when the dispensed droplet reaches sensor module 300. Computer 100 may then calculate the drop velocity and compare it to a known good drop velocity. The known good drop velocity for a particular application may be determined by experimentation, for example. If the nozzle 121 employs a piezoceramic actuator, the electrical signal applied on the actuator may be varied to achieve the desired drop velocity. The electrical signal needed to be applied on the actuator to dispense droplets at the desired velocity may be stored in computer 100, and then used on the nozzle 121 during operation.

The just mentioned calibration process may be used for each nozzle 121 so that all nozzles 121 dispense droplets having relatively the same mass, drop velocity, or both. As can be appreciated, this in turn will help improve film thickness uniformity on the wafer.

Referring now to FIG. 3B, there is shown an IC manufacturing equipment 350A in accordance with another embodiment of the present invention. Equipment 350A is similar to equipment 350 shown in FIG. 3A except for the addition of a link 301 coupling sensor module 300 to computer 100. Link 301 allows sensor module 300 to provide feedback signals to computer 100. The feedback signals may include, without limitation, signals indicative of detected drop mass, drop velocity, or both. This helps integrate the calibration process with the deposition process. For example, computer 100 may position print head 120 over sensor module 300, calibrate each nozzle 121 of print head 120, position print head 120 over wafer 102, and then dispense material on wafer 102.

FIG. 4 shows a schematic diagram of a sensor module 300A in accordance with an embodiment of the present invention. Sensor module 300A is a specific embodiment

of sensor module 300 shown in FIGS. 3A and 3B. As shown in FIG. 4, sensor module 300A includes a bias voltage 401, a sensor 410, and a charge sensitive amplifier 420. Sensor 410 further includes a plate 411A and a plate 411B that, in effect, form a capacitor. In one embodiment, plates 411 (i.e., 411A, 411B) are thin blades of electrically conductive material. The surfaces of plates 411 may be placed in parallel, with a gap in the order of the distance between nozzles 121 (e.g., ~100 to 1000 microns).

Bias voltage 401 applies a voltage (e.g., ~100 to 1000V DC) on plate 411A through resistor 402. Plate 411B is coupled to amplifier 420.

In one embodiment, plates 411 (i.e., 411A, 411B) are separated by air. Because the dispensed droplets have dielectric constants higher than air (e.g., about 7 to 80, depending on the material), a droplet passing between plates 411 changes the capacitance of sensor 410. The resulting charge on sensor 410 is sensed by amplifier 420, which then generates a corresponding output signal on terminal 504. The signal on terminal 504 may be processed to detect drop mass and drop velocity. For example, the amplitude of the output signal contains information about the relative mass of the just detected droplet, and may thus be used to sense drop mass. As another example, the delay time between the firing of the nozzle 121 and the resulting output signal on output terminal 504 may be used to calculate drop velocity. Thus, the output signal at terminal 504 may be used to calibrate for drop mass, drop velocity, or both.

As mentioned, the output signal at terminal 504 may be used to sense relative drop mass. However, the output signal may also be used to sense absolute drop mass

by, for example, performing measurements correlating the amplitude of output signals with actual (i.e., measured with another instrument) droplet mass.

Sensor module 300A provides several advantages. First, because sensor 410 is relatively simple in construction, it does not need a lot of periodic cleaning and maintenance. Second, sensor module 300A may be used not just for calibration but also for testing if a nozzle is functioning. As can be appreciated, both calibration and testing may be performed in-situ. Third, sensor module 300A may be integrated in an automatic feed back system (e.g., see FIG. 3B) to allow for automatic calibration of the nozzles. Fourth, the relatively short measurement time of sensor module 300A allows measurement of relative volume of volatile fluids (e.g., spin-on coating materials) that are ordinarily hard to measure because they readily evaporate when dispensed. The short measurement time also facilitates collection of large amounts of data from which accurate averages may be extracted.

FIG. 5 shows a circuit diagram of a sensor module 300B in accordance with an embodiment of the present invention. Sensor module 300B is a specific embodiment of sensor module 300 shown in FIGS. 3A and 3B. As shown in FIG. 5, sensor module 300B includes a sensor 410 having plates 411A and 411B. In the example of FIG. 5, plates 411 are two parallel thin plates. In one embodiment, plates 411 are fine strips of sheet metal spaced ~300 microns apart and each having a sensing area of about 1.5mm x 2.0mm. Droplets to be sensed pass through the air gap between plates 411. Plate 411A is coupled to a bias voltage applied on a terminal 505. In one embodiment, the bias voltage is about 200 volts. Plate 411B is coupled to a transistor 521. In one embodiment, transistor 521 is a FET transistor employed to increase the input

impedance of a charge sensitive amplifier 520. Amplifier 520 may be of the same type as, for example, the A250 charge sensitive preamplifier available from Amptek, Inc. of Bedford, Massachusetts (URL:<http://www.amptek.com>).

In FIG. 5, power supplies (not shown) coupled to terminals 501 and 502 provide input power to amplifier 520. A terminal 503 is coupled to a ground reference.

Still referring to FIG. 5, a droplet dispensed through plates 411 changes the capacitance of sensor 410. The resulting charge is compensated for by amplifier 520 through its feedback path to the gate of transistor 521. This results in an output voltage pulse on terminal 504. The output voltage pulse on terminal 504 may then be processed to determine drop mass, drop velocity, or both.

FIG. 6A shows a perspective view of a chassis assembly 600 for a sensor module in accordance with an embodiment of the present invention. Chassis assembly 600 includes a sensor block 601, a housing 602, and a cover plate 604.

FIG. 6B shows a magnified view of a portion of sensor block 601 denoted as area 660 in FIG. 6A. As shown in FIG. 6B, sensor block 601 includes two parallel grooves where a pair of plates 411 are inserted. Droplets passing between plates 411 fall to the bottom of channel 621. A drain (not shown) at the bottom of channel 621 allows droplets to be flushed out of the sensor module. Sensor block 601 is advantageously of a material that is impervious to the droplets. In one embodiment, sensor block 601 is made of Ertalyte, PET-P material from Quadrant Engineering Plastic Products.

Referring back to FIG. 6A, a cover plate 604 serves as a shield and goes over sensor block 601. A hole 661 in cover plate 604 allows droplets to pass through and go between plates 411. Plates 411 may be soldered to wires coupled to circuitry (e.g., see FIG. 5) inside an electronic enclosure 603. Advantageously, electronic enclosure 603 is shielded to minimize electrical interference to the circuitry. Holes 610 and 611 in housing 602 allow wiring to be coupled to circuitry inside electronic enclosure 603.

Improved techniques for sensing droplet characteristics have been disclosed. While specific embodiments have been provided, it is to be understood that these embodiments are for illustration purposes and not limiting. Many additional embodiments will be apparent to persons of ordinary skill in the art reading this disclosure. Thus, the present invention is limited only by the following claims.